REPORT No. 533

DISTRIBUTION AND REGULARITY OF INJECTION FROM A MULTICYLINDER FUEL-INJECTION PUMP

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SUMMARY

A six-cylinder commercial fuel-injection pump was adjusted to give uniform fuel distribution among the cylinders at a throttle setting of 0.00038 pound per injection and a pump speed of 750 revolutions per minute. The throttle setting and pump speed were then varied through the operating range to determine the uniformity of distribution and regularity of injection.

The variation in distribution among the cylinders reached a maximum of ±17 percent at low pump speeds and one-tenth throttle setting. Above one-half throttle the variation was not more than ±3.0 percent. No effect on the distribution was produced by a change in the type of injection valve or injection-valve spring. As the valve-opening pressure or the residual pressure in the injection tube was reduced to a very low value the regularity of injections increased. The distribution was little affected. A stiffer injection-valve spring also produced more regular injections. Poor seating of the injection-valve stem caused a variation in the residual pressure in the injection tube.

INTRODUCTION

With the introduction of the fuel-injection spark-ignition engine it becomes increasingly important to study the distribution of fuel from a multicylinder fuel-injection pump. In the compression-ignition engine a variation in fuel distribution does not prove serious except from the standpoint of loss of power or a smoky exhaust. In a spark-ignition engine, however, variations in the fuel quantity delivered to the different cylinders may result in overheating of the engine and in excessive fuel consumption as well as in loss of power. The charge being stratified in the compression-ignition engine, the rate of burning is not greatly affected by the air-fuel ratio. In the spark-ignition engine the charge is not stratified to any great extent. Consequently, a lean mixture results in slow burning and in overheating because of the high exhaust-gas temperatures.

One of the advantages claimed for the fuel-injection system as opposed to the carburetor has been that the fuel distribution to individual engine cylinders would be considerably improved. Tests reported by Campbell (reference 1) have shown that the distribution from a nine-cylinder injection system designed to operate on gasoline varied between ±0.5 to ±2.0 percent depending on the operating conditions. In this same paper, Campbell discusses the advantages to be expected from using a fuel-injection system with a spark-ignition engine. Although it is certainly true that the fuel-injection system provides more possibility of distribution control, no data on extended tests have been presented to show the actual variation in fuel quantity delivered from a multicylinder injection system over a wide range of operating conditions. It is the purpose of this report to present such data. The tests discussed herein are part of a general investigation of fuel-injection systems being conducted by the N. A. C. A. at Langley Field, Va. The tests were conducted during the latter part of 1933 and the early part of 1934.

APPARATUS AND METHODS

The six-cylinder fuel-injection pump with which the distribution tests were made was also used in the tests reported in references 2 to 5, inclusive. The pump (fig. 1) is of the constant-stroke type, the throttle control being obtained by rotating the pump plunger and so controlling the duration of injection by the relationship between the helix on the plunger to the ports in the sleeve. This pump was particularly well suited for these tests because of its extensive service. During the tests referred to the pump had been operated for approximately 1,000 hours. Although most of these test were conducted with diesel fuel, some of them were conducted with water and some with S. A. E. 30 lubricating oil, approximately 30 hours each (reference 5). In addition, the pump has been used for engine tests employing fuels having viscosities ranging from that of diesel fuel to that of gasoline. Except for a brief series of tests when the pump was new, the majority of tests have been on a single cylinder of the pump. Cylinders 1 and 6 have been used most extensively and cylinders 3 and 4 the least. During the earlier tests the pump was continually started and stopped; consequently the pump has seen particularly hard service.

When the pump was purchased, the distribution was measured and found to be ±2 percent over the

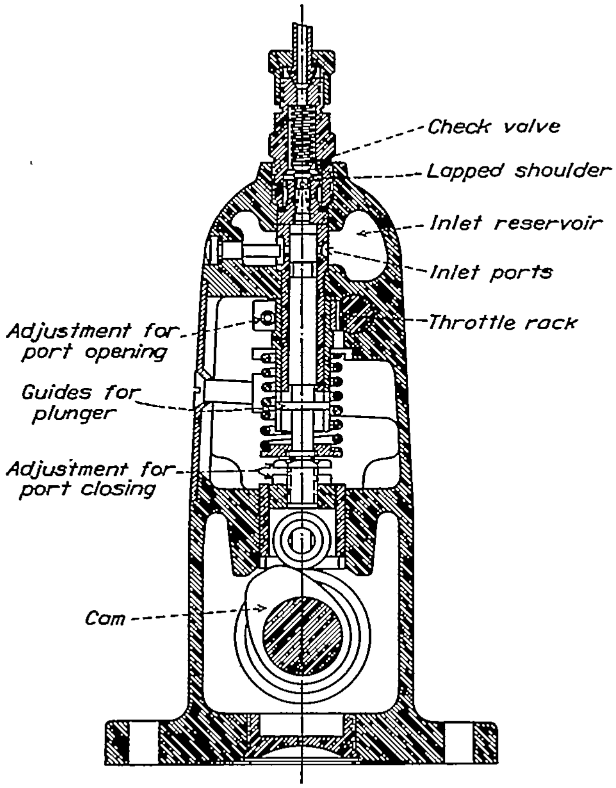

FIGURE 1.—Cross section of pump.

operating range. At the start of the present tests the pump was first disassembled, adjusted, and reassembled so that the positions of the control surfaces relative to the cams and to each other were correct. The necessary adjustments were made without any alterations to the parts of the pump.

The injection valves investigated were of the automatic spring-loaded type shown in figure 2. The injection valve that was used most extensively had a single 0.020-inch orifice. Two injection-valve springs, designated 1 and 2, with spring scales of 780 and 3,480 pounds per inch, respectively, were tested. In order to compare the effect of different nozzle seats, a pintle-type injection valve was also tested having a spring scale of 800 pounds per inch.

The diesel fuel employed had a viscosity of 0.102 poise at 20° C. and a specific gravity of 0.85. All the fuel was centrifuged before being placed in the fuel tank. Gasoline was not tested because of the fire hazard. It has been shown (reference 5) that the operation of the injection system would be the same with either gasoline or diesel fuel.

Three different test procedures were used. An injection-valve-stem stop was used in the first and second series of tests but not during the third. In the first series of tests, the rates of discharge were measured with the injection valve operated in turn from each pump cylinder. The rate-of-discharge apparatus and its method of operation has been described in reference 3. The apparatus consists essentially of a means of intercepting the fuel discharged for each ½° of pumpshaft rotation. In the second series of tests, the total fuel quantity discharged from each pump cylinder, using the same injection valve, was determined by discharging the fuel into a bottle and weighing the fuel discharged for a measured number of pumpshaft revolutions. In the third series of tests, the motion of the injection-valve stem was recorded optically by a method similar to that described in references 2 and 6. The same throttle setting and pump cylinder were used in obtaining the stem-lift records. Because this optical method provides a simple and economical method of investigating the regularity of injection from a fuel pump, it will be described in some detail.

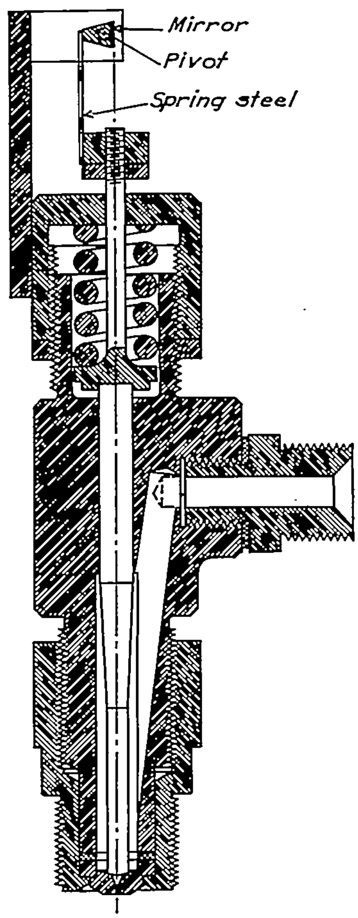

FIGURE 2.—Cross section of injection valve and mirror attachment.

Figures 2 and 3 show the optical arrangement of the injection valve and the injection pump. The injection-valve-stem follower is extended through the injection-valve cap. The outer end of the follower is threaded and 2 nuts, 1 for locking purposes, are screwed onto the threads. A piece of spring steel 0.006-inch thick is attached to the outer nut. The other end of the spring steel is attached to the small mirror support. The mirror support is pivoted on the second support, which is in turn fastened to the injection-valve cap. Any linear motion of the injection-valve stem is imparted to the mirror support as a rotating motion. A light beam from an 18-ampere 6-volt ribbon filament bulb is directed, but not focused, on the small mirror. Any motion of the mirror will therefore change the angle of incidence and reflection of the beam, the deflection indicating the amount that the injection-valve stem has been lifted. The reflected light beam is in turn directed onto a mirror mounted on the pumpshaft. The rotation of the shaft causes the light beam to turn at twice the pumpshaft speed (because both the angles of incidence and reflection are changed). This reflected beam is brought to a focus on a celluloid screen bent in the shape of an arc and mounted at its radial distance from the pumpshaft. For permanent records the reflected beam is focused on a photographic film. The motion of the injection-valve stem, as indicated in figure 3, is recorded

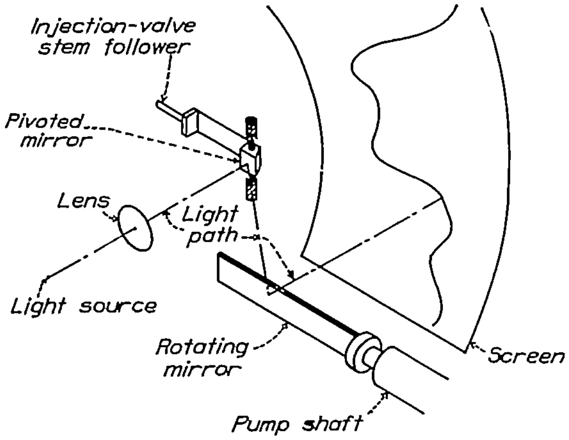

FIGURE 3.—Optical arrangement for obtaining a record of the motion of the injection-valve stem.

by the light beam in a direction parallel to the pumpshaft and the angular rotation of the pumpshaft is recorded in a direction normal to the pumpshaft. With this arrangement the observer is given an impression of a continuous record of the time-lift diagram of the injection-valve stem. Since a new record is traced for each successive injection, any variation in the injection can be observed from the motion of the injection-valve stem. The apparatus will show whether a variation is inherent in the design of the system, in which case a certain series of two or more records will repeat itself, or whether the variation is caused by some less steady cause, in which case there will be a number of different records occurring in no given order.

TESTS RESULTS AND DISCUSSION

FUEL DISTRIBUTION

The rates of discharge from all six cylinders, after the adjustments had been made, are shown in figure 4. The positions of zero pump degrees for the 6 cylinders represent arbitrary points taken at 60-pump-degree intervals to compensate for the 60° phase interval between the 6 cylinders. The total variation of the fuel quantity is ±1.5 percent and the variation in injection timing is less than ±0.5 pumpshaft degree. The shape of the curves is also seen to be quite similar, showing the variation in the average rates of discharge to be negligible.

Stem-lift records for each of the six pump cylinders for several pump conditions are shown in figures 5 and 6. The similarity of the records, even to the small oscillations caused by the deflection of the different parts of the recording system, is noteworthy. At low speed and low throttle settings the variation in the records becomes proportionally greater and the result is shown by the percentage increase in the variation between the different pump cylinders. Figure 6 shows that the total variation in distribution was ±2 percent considering all the cylinders and ±1 percent considering cylinders 2, 3, 4, and 5, which had had the least service.

In order to determine the effect of the injection-valve seat on the average rates of discharge, an injection valve was tested that had seen considerable service as a pressure-relief valve on another injection system. The rates of discharge (fig. 7) were changed to some extent by polishing the valve seat. An even greater change was obtained, however, by allowing

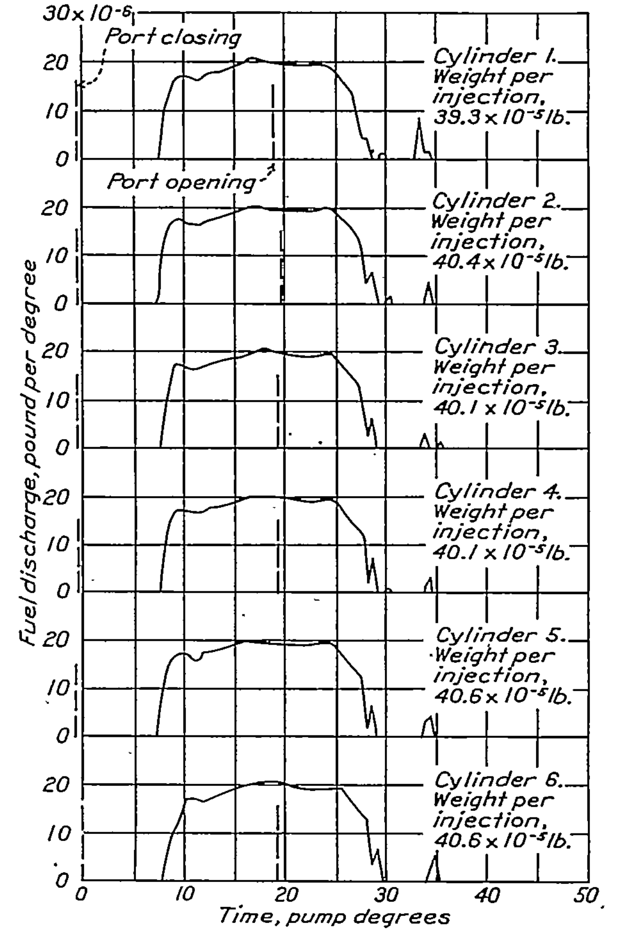

FIGURE 4.—Comparison of rates of discharge from different cylinders. Pump speed, 750 r. p. m.; 0.020-inch orifice; v. o. p., 3,000 lb. per sq. in.

the polished seat to be run in. Three runs made under this last condition showed similar rates except for the initial period of injection. The differences in the initial rates of injection before and after the injection valve was run in are caused by the poor seal at the seat when the valve was first tested. This faulty seating caused the residual pressure between injections to fall below its full value causing the initial rates of discharge to be decreased. Even with the leaking seat,

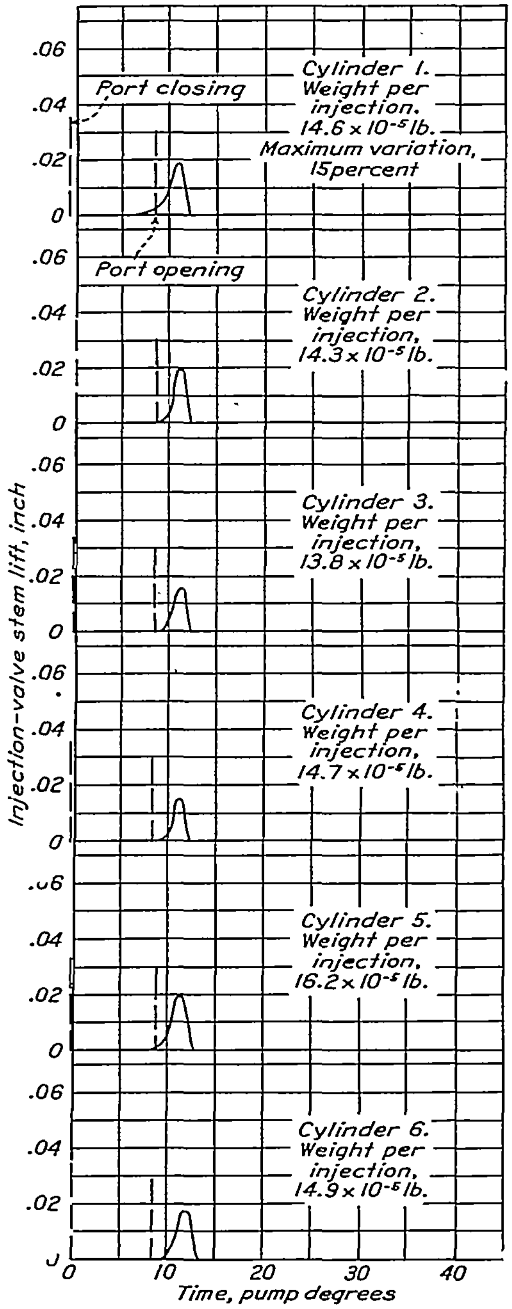

FIGURE 5.—Stem-lift diagrams from different cylinders of multicylinder pump for 250 r. p. m. and one-ninth throttle setting. Check valve with lapped shoulder; injection every other revolution; v. o. p., 2,500 lb. per sq. in.; injection-valve spring 1.

the total quantity of fuel injected did not show much variation.

The previous test having shown that a multicylinder pump could be adjusted for one throttle setting and speed to give excellent distribution, the next tests were made to determine what the distribution would be over a number of different conditions of throttle settings and pump speeds. The actual rates of discharge were not determined in these tests. Instead, the fuel from each cylinder was discharged into a bottle and weighed. The same injection valve was used for each cylinder. Figure 8 shows the results for fuel quantities from 0.0001 to 0.0006 pound per injection, speeds from 250 to 1,000 revolutions per minute, and with two different injection valves. It is seen that with each valve the distribution is best at a speed of 750 revolutions per minute and with a fuel quantity of 0.0004 pound per injection, the conditions for which the pump had been adjusted. The percentage variation is greatest at low speeds and low throttle settings. At speeds of 500 revolutions per minute, or greater, and throttle settings of 50 percent pump capacity, or greater, the variation was never more than ± 3 percent. The curves show that it is difficult to adjust the pump for correct distribution under one condition and have the adjustment hold under all conditions. The differences in fuel quantities injected are caused by the variations in the pump dimensions and in the variations in the leakage between the plunger and the sleeve. The results of the last-mentioned cause should be inappreciable except at the light loads and the low speeds.

Figure 9 shows that changing the injection-valve opening pressure has little effect on the distribution with the exception that at the lower throttle settings the curves for the separate cylinders do not show the same tendency to intersect as they do at the higher opening pressures. Consequently, at the lower valve opening pressures it is probable that a better adjustment could be made for those conditions at which the variation in distribution is the worst. The greatest numerical variation in distribution occurs at full throttle and low speed, indicating that leakage plays an important part under these conditions. A comparison of figures 8 and 9 shows that with cylinder 6 the leakage at the low speed and high throttle setting increased considerably as the injection-valve opening pressure increased.

It should also be mentioned that at the setting of 0.0004 pound per injection at which the leakage was the least the area of lapped surface sealing the fuel under high pressure from the intake manifold was a maximum. At higher and lower throttle settings one edge of the port is closer to the edge of the helix on the plunger and greater leakage will therefore result. Neglecting the high throttle, low-speed condition, the maximum variation in quantity was about 0.00002 pound per injection or 0.00065 cubic inch.

An injection pump under ordinary service in which all cylinders are operated for the same length of time should give even better distribution than that recorded in these tests.

REGULARITY OF SUCCESSIVE INJECTIONS

A complete quantitative analysis of the injection-valve-stem lift records was not made. The records themselves are presented to show the degree of regularity of the injections under different conditions of operation. When a single curve is shown it signifies that under that condition the stem motion, and therefore the injection cycle, repeated itself in each successive cycle. When such was not the case several different curves, the number depending on the number recorded, are presented. At the conditions for which two curves are shown, the odd cycles repeated themselves following one of the curves and the even cycles followed the other curve.

At certain pump speeds, as many as 3 or 4 regular cycles were obtained. At low pump speeds and low throttle settings, the pump injected only on every other revolution. Tests measuring the fuel quantity discharged under this condition have been made by Hetzel (reference 7). Hetzel has shown that the minimum quantity which can be injected on each cycle is dependent on the pump speed, the injection-valve opening pressure, and on the volume of fuel between the injection valve and the pump. He has made the mistake, however, of assuming that under some conditions pressure waves do not play a noticeable part. Any injection system employing a volume of fuel under pressure between the source of that pressure

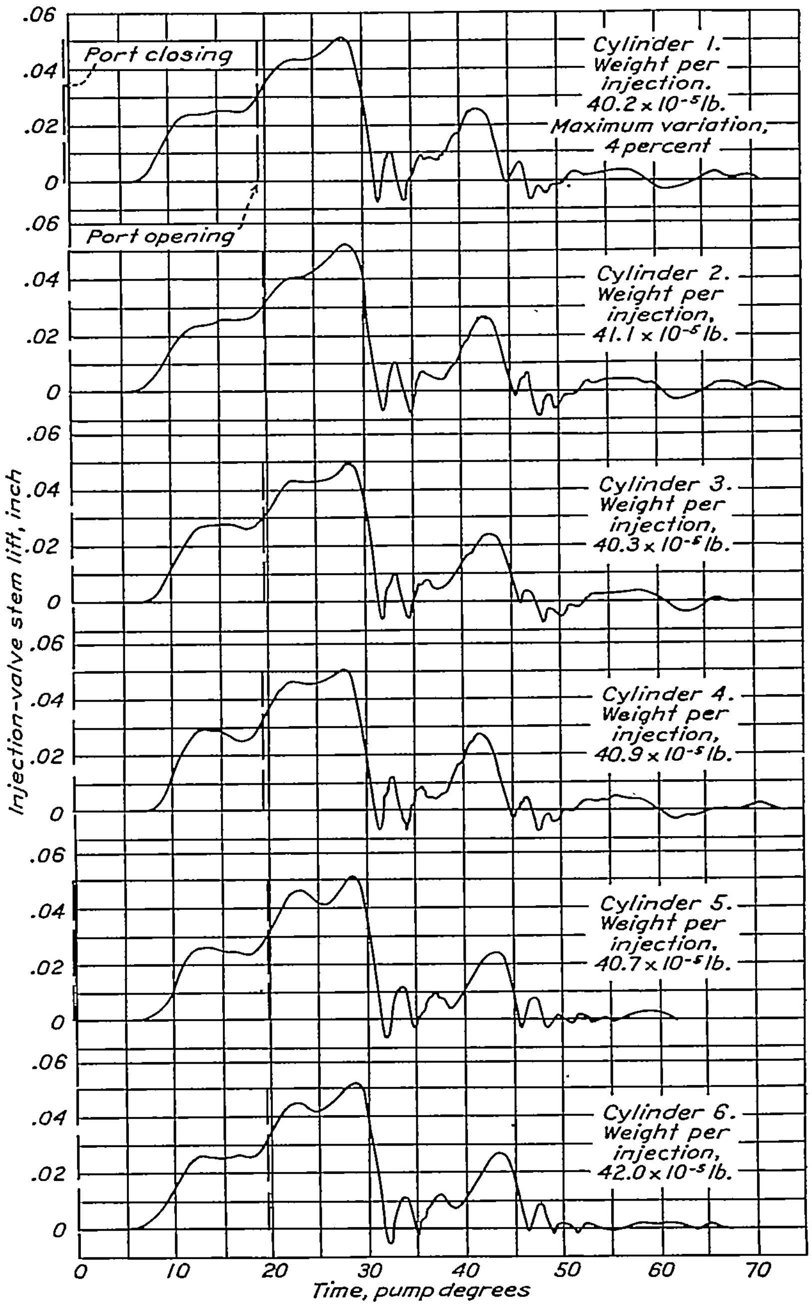

FIGURE 6.—Stem-lift diagrams from different cylinders of multicylinder pump for 1,000 r. p. m. and two-thirds throttle setting. Check valve with lapped shoulder; v. o. p., 2,500 lb. per sq. in.; injection-valve spring 2.

and the discharge orifice must of a necessity operate with pressure waves. The magnitude of the waves may, of course, vary. As the injection-pump plunger travels upward and the port in the sleeve is closed, a pressure wave is started through the injection tube to the discharge orifice. If the initial wave front is of

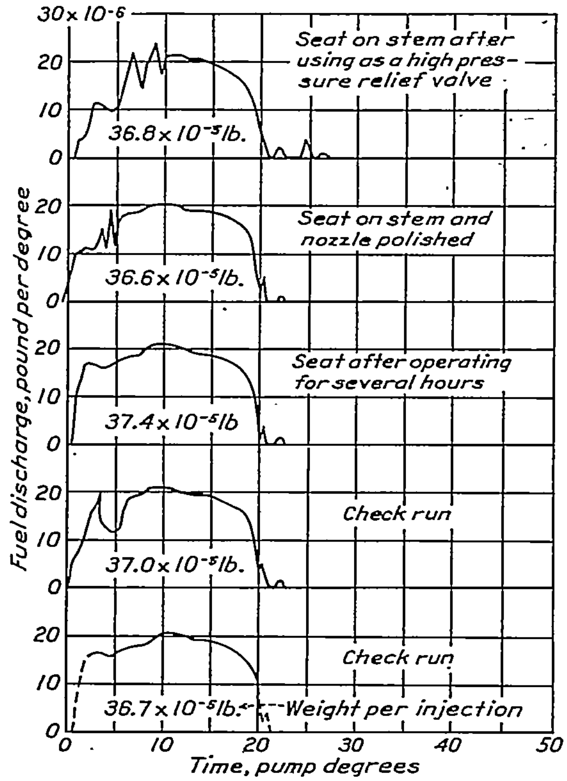

FIGURE 7.—Effect of nozzle seat on the rate of discharge. Pump speed, 750 r. p. m.; 0.020-inch orifice; v. o. p., 3,600 lb. per sq. in.; cylinder 6.

sufficient intensity to open the injection valve, the injection starts as soon as the wave front reaches the valve. If the wave front is not of sufficient intensity to open the injection valve, the entire wave is reflected through the injection tube. Since, in general, an injection pump operates at an increasing rate of plunger displacement during the injection period, the intensity of the wave front continually increases. Any time that this primary wave front reaches a value of sufficient intensity to open the injection valve, injection starts. The conditions, however, may be such that the injection valve is not opened until this primary wave is reenforced by a reflected wave. In this case the minimum injection lag is three times the time required for the wave to traverse the length of the injection tube. Because of this factor, neither the time lag of injection nor the minimum quantity injected is necessarily a function of the pump speed but may, as Hetzel found, show certain discontinuities when plotted as a function of the pump speed. In fact, the discontinuities shown by Hetzel probably occurred at the pump speed for which the primary wave front became of sufficient intensity to open the injection valve without the aid of reflected wave fronts. This phenomenon is clearly shown in the records obtained in the present series of tests.

Figure 10 (a) shows the injection-valve-stem lift records at different speeds and with injection-valve spring 1. In these tests the entire speed range was slowly traversed and records were taken at the various speeds shown. In figure 11 (a) the maximum injection pressure and fuel per injection under the same conditions are plotted. At a pump speed of 169 revolutions per minute two injections resulted, the even injections being designated by the solid line and the odd by the dashed line. Each injection was started by a small lift of the stem lasting for a single pressure-wave cycle; that is, for sufficient time for the wave to travel twice the length of the injection tube. The stem was then lifted clear of the seat and the main injection took place. The preliminary small stem lift signified that the primary wave front was not sufficiently strong to lift the stem more than a very slight amount and that it was necessary for this wave to be reenforced by the secondary wave front. No

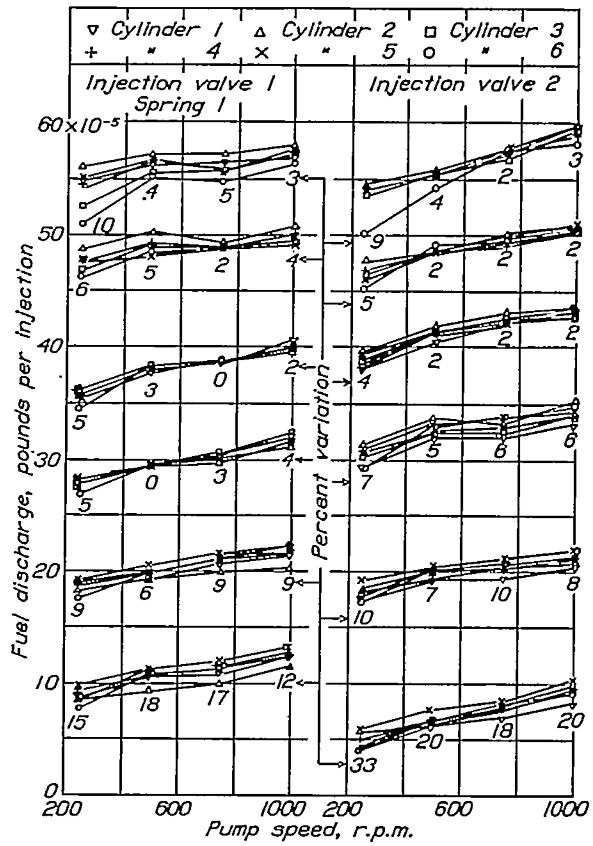

FIGURE 8.—Effect of pump speed on distribution at different throttle settings and with different injection valves. 0.020-inch orifice; v. o. p., 3,600 lb. per sq. in.

calibration of the position of the port opening and closing with respect to the beginning of the stem lift was obtained for figure 10 (a). The positions as shown on figure 10 (b) can be used with little error.

With the even injections, the hydraulic energy was then dissipated so fast that the stem again seated and the process was repeated. With the odd injections the time lag was much longer, signifying a lower residual pressure in the injection tube after the even cycles and, consequently, cut-off occurred before any second injection could take place. As a result of this action, the residual pressure in the injection tube was increased after the odd cycles and the even injection therefore started earlier, as shown by the curves. At a pump speed of 235 revolutions per minute, the phenomena reoccurred. The second stem lift of the even cycles shows the port opening to be affecting the stem-lift record. It does not affect the irregularity of the cycles. As the pump speed was further increased the injection lag was sufficiently great that the second stem lift of the even cycles was partly cut off owing to the opening of the ports. Opening of the ports before the pressure causing the second stem lift was dissipated by injecting allowed a higher residual pressure to be trapped in the injection tube. This pressure was gradually built up, after the even injections, as the pump speed increased until, at a pump speed of about 248 revolutions per minute, the residual pressures of the odd and even cycles became the same and regular injection resulted.

At the pump speed of 248 revolutions per minute two injections occurred on every cycle, but the second injection was now much less than the first because of its late start with respect to opening of the by-pass port for injection cut-off. At this speed the preliminary injection was still equal in duration to a complete wave cycle. As the pump speed was increased to 269 revolutions per minute, irregular injection again took place. At 269 revolutions per minute the main injection started with the first lift of the injection-valve stem. This fact signifies that at this speed the primary wave front was now of sufficient intensity on the even injections to lift the stem clear of the seat without the reflection and consequent addition of the secondary wave front. As a result, more fuel was discharged and the residual pressure was lowered and on the odd injections there was a single stem lift with the increase in the injection lag. As the pump speed was increased the second stem lift of the even cycles was again affected by the port opening and regular injections occurred at a pump speed of about 305 revolutions per minute. At 305 revolutions per minute there was again a preliminary lift of the stem and two injections on each revolution. At 319 revolutions per minute the injections followed three different courses on the first, second, third, etc., injections. The causes of the irregularities at the pump speeds of 319 to 327, 420 to 435, 629, and 860 revolutions per minute are not clearly shown. They were obtained when the pump speed was gradually increased until the pressure wave front, shown at 305, 336, 507, and 824 revolutions per minute reached the limit of the stem-lift curve. A slight increase in pump speed above this value produced irregular injections. No attempt is made to analyze each of these cycles except to state that they are caused by the cyclic variation in the residual pressure in the injection tube. After 629 revolutions per minute such variations that did occur were small. The curves of average fuel per injection and maximum pressure show that the irregular injections were accompanied by sudden changes in both of these factors.

Increasing the scale and consequently decreasing the natural surging period of the injection-valve spring by using spring 2 (fig. 10 (b)) improved the regularity

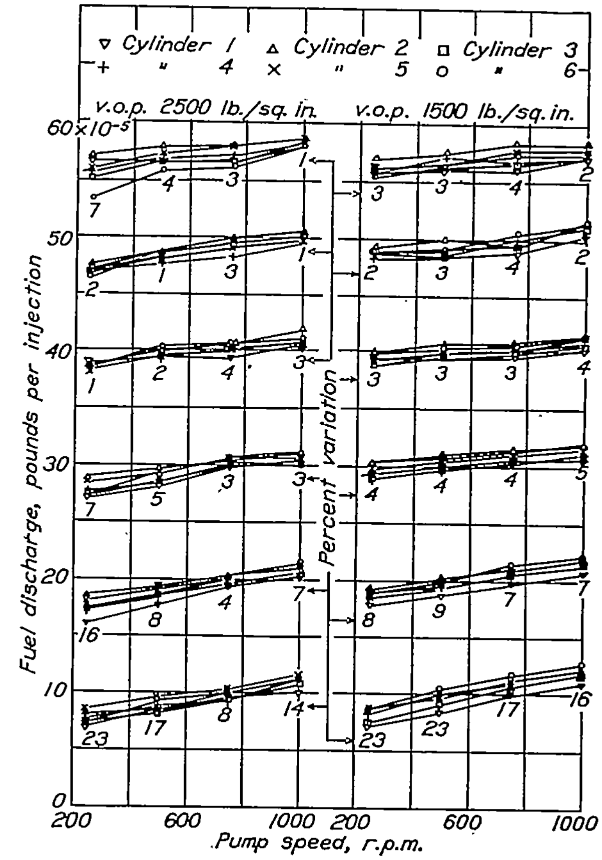

FIGURE 9.—Effect of pump speed on distribution at different throttle settings and at different injection-valve opening pressures. 0.020-inch orifice; injection valve 1; injection-valve spring 2.

of the injections. As has been shown in reference 2, the pressure in the injection tube may, if the injection-valve-stem lift is considerable, drop in less time than that required for the stem to return to its seat. As a result the residual pressure in the injection tube is less than would have been the case had the stem closed more quickly. The same effect can be obtained by mechanically limiting the lift of the injection-valve stem. Figure 11 (b) shows the variation in injection lag with pump speed. The fact that the lag is not directly a function of speed is clearly shown. With the stiffer spring the average fuel quantity injected also shows less variation as the pump speed is increased.

Decreasing the injection-valve opening pressure further increases the regularity of injection for two

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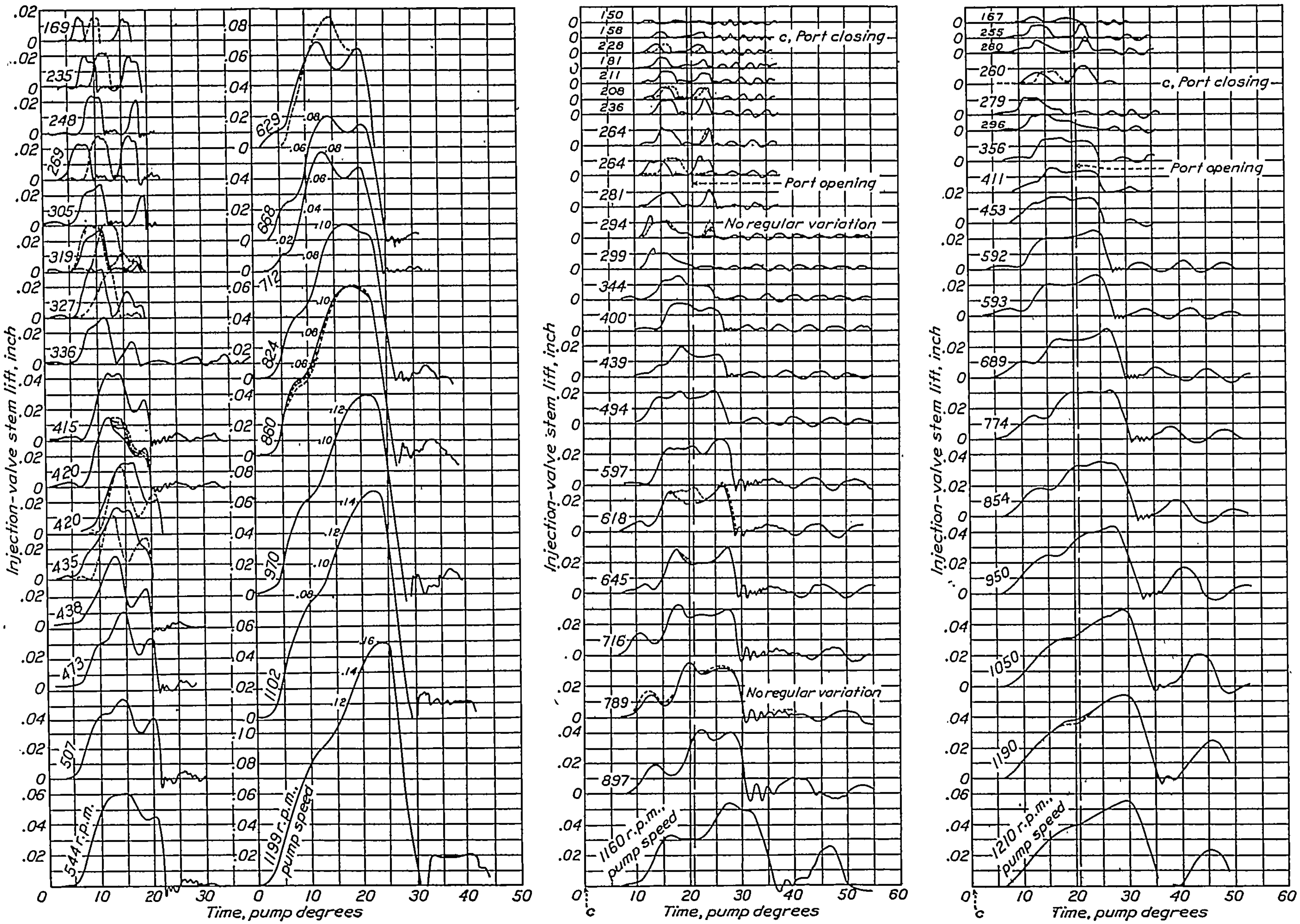
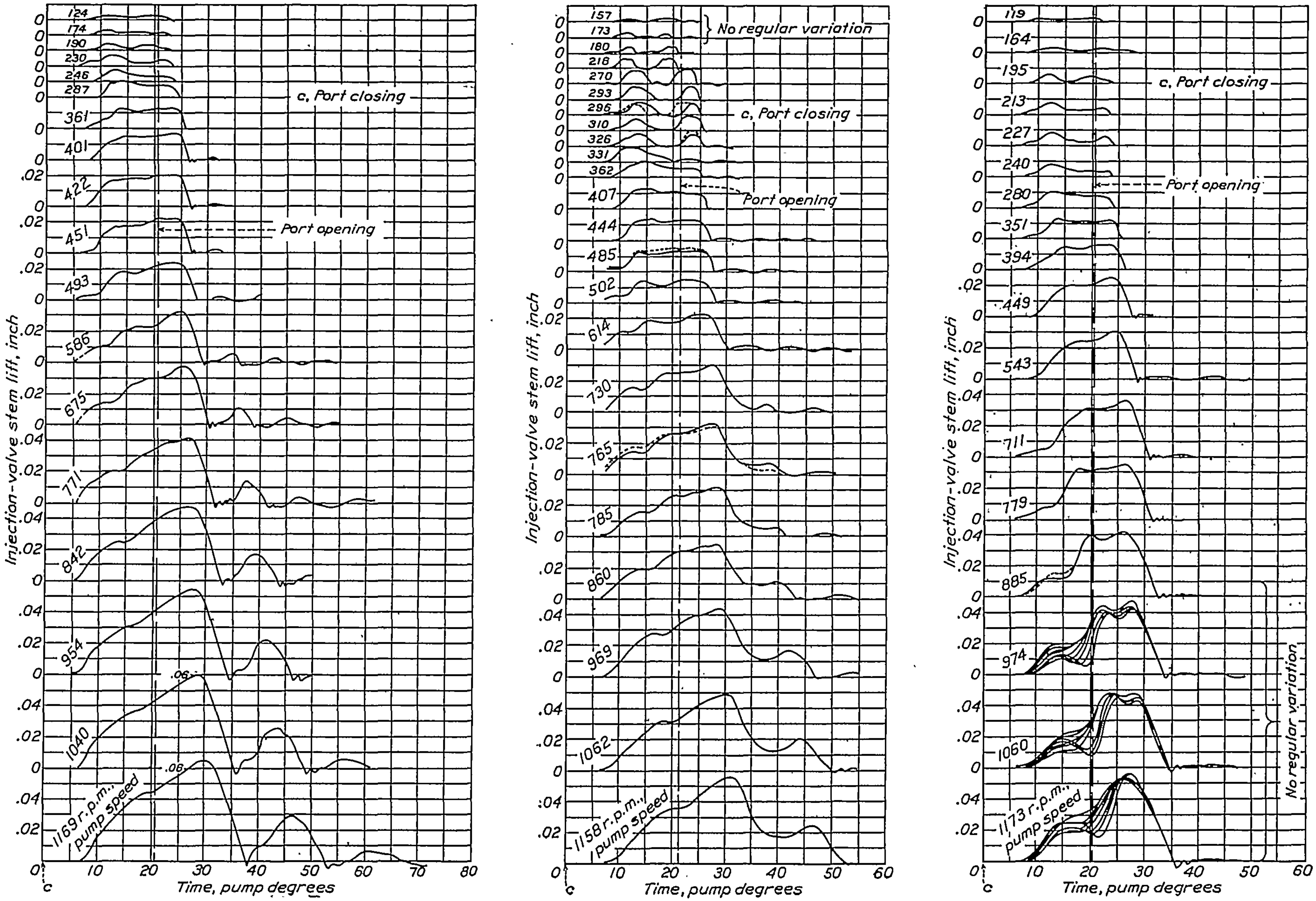


(a) Check valve with lapped shoulder; v. o. p., 3,600 lb. per sq. in.; injection-valve spring 1.

(b) Check valve with lapped shoulder; v. o. p., 3,600 lb. per sq. in.; injection-valve spring 2.

(c) Check valve with lapped shoulder; v. o. p., 2,500 lb. per sq. in.; injection-valve spring 2.

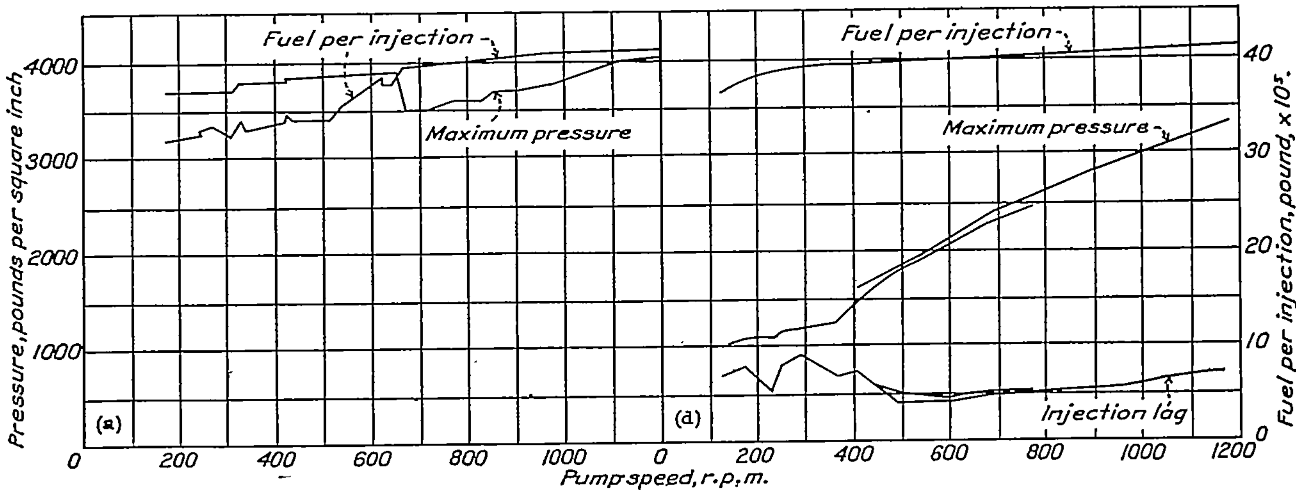


(d) Check valve with lapped shoulder; v. o. p, 1,500 lb. per sq. in.; injection-valve spring 2.

(e) Check valve without lapped shoulder; v. o. p., 3,150 lb. per sq. in.; injection-valve spring 2.

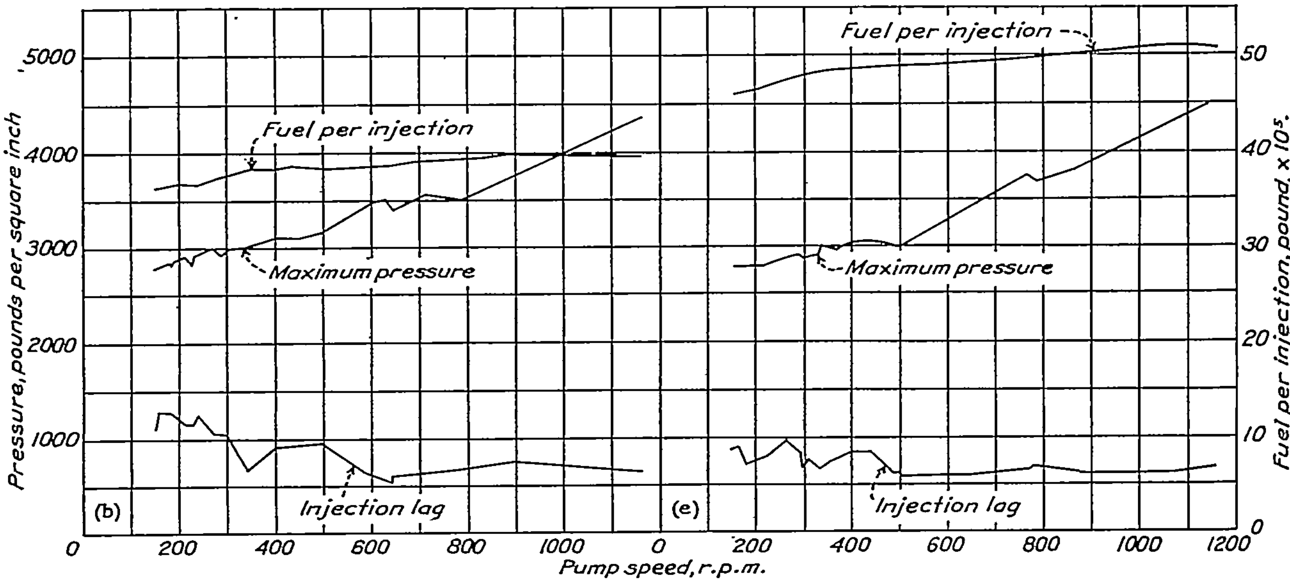
(f) No check valve; v. o. p., 1, 500 lb. per sq. in.; injection-valve spring 2.

FIGURE 10.—Effect of pump speed on the injection-valve stem motion.



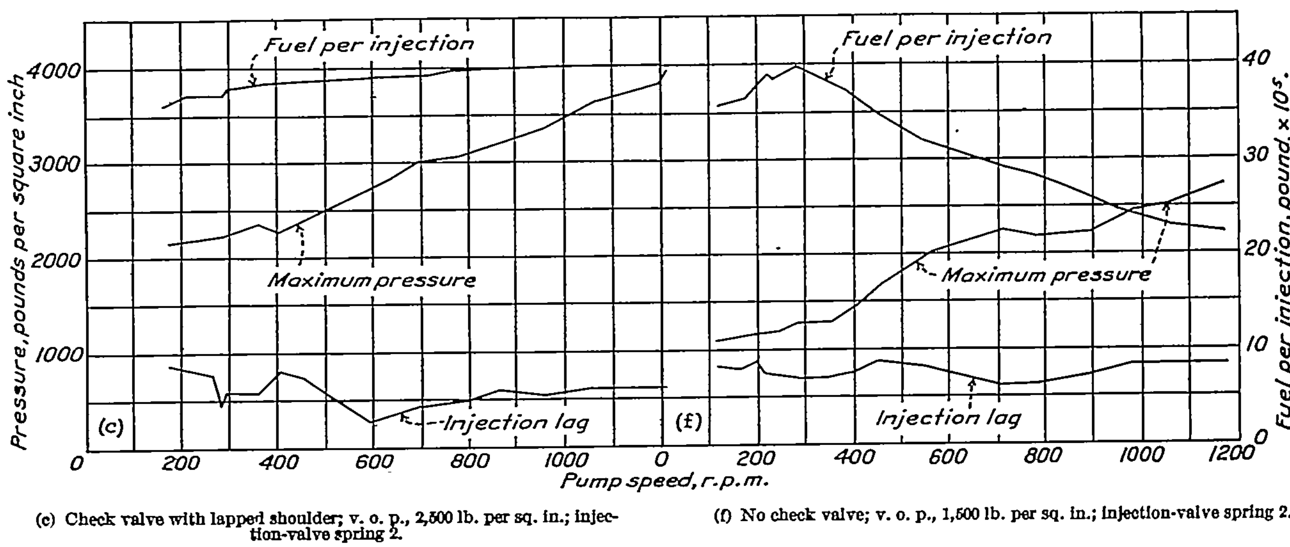
(a) Check valve with lapped shoulder; v. o. p., 3,600 lb. per sq. in.; injection-valve spring 1.

(d) Check valve with lapped shoulder; v. o. p., 1,500 lb. per sq. in.; injection-valve spring 2.



(b) Check valve with lapped shoulder; v. o. p., 3,600 lb. per sq. in.; injection-valve spring 2.

(e) Check valve without lapped shoulder; v. o. p., 3,150 lb. per sq. in.; injection-valve spring 2.



(c) Check valve with lapped shoulder; v. o. p., 2,500 lb. per sq. in.; injection-valve spring 2.

(f) No check valve; v. o. p., 1,500 lb. per sq. in.; injection-valve spring 2.

FIGURE 11.—Effect of pump speed on the injection lag, maximum pressure, and fuel discharged per injection.

reasons. With the lower injection-valve opening pressure, fewer reflections of the primary wave front are required before the injection valve opens; consequently there is less compression of fuel at the start of injection. As the residual pressure in the injection line decreases, the residual pressure approaches the dynamic pressure in value and the injection becomes more dependent on the dynamic pressure. Figure 10 (c) shows that, at an injection-valve opening pressure of 2,500 pounds per square inch, the oscillating injections took place only at 260 revolutions per minute; when the pressure was further decreased to 1,500 pounds per square inch (fig. 10 (d)), the injections were regular at all speeds from 124 to 1,169 revolutions per minute. The stem-lift records of figure 10 (d) and figure 11 (d) were taken on successive days. The discontinuities of the maximum pressure and injection-lag curves were caused by a 10° F. variation in fuel temperature. By a comparison of 10 (b) and 10 (c), it is seen that as the injection-valve opening pressure was decreased the tendency for the small initial discharge to take place was also decreased, but the secondary discharges at the end of injection increased in intensity and, as has been shown in references 2 and 8, the injection pressure, and therefore the atomization, also decreased.

If an open nozzle is used there will be no variation in the injections caused by variation in the residual pressure because the residual pressure will, in every case, be extremely low. Data on the rates of discharge with open nozzles have been given by Third and Higgins (reference 9) and by Davies and Giffen (reference 10). In reference 10 data are also given for closed nozzles; but either the injection-valve opening pressure was too high or the discharge-orifice diameter too large, for each injection consisted of a series of discharges. (See also reference 3.)

With the injection pump tested, the check valve between the injection pump and the injection tube had a lapped shoulder that dropped the residual pressure in the injection tube to a value below the injection-valve closing pressure because the closing of the check valve increased the volume between the pump and the injection valve. When this shoulder was removed, the residual pressure was more nearly equal to the injection-valve closing pressure and therefore more nearly equal to the injection-valve opening pressure. As a result, the pump did not have to build up as much pressure to open the injection valve and the injection lag was decreased. Also, the residual pressure became more constant because of the fewer oscillations in the injection tube for the same fuel quantity and the injections therefore became more regular. The cut-off of injection became slower and there was no cessation of injection between the main and secondary discharges. The speed of the cut-off was decreased, particularly at the high pump speeds, under which conditions the rate of opening of the by-pass ports became a more important factor (fig. 10 (e)).

When the check valve was entirely removed (fig. 10 (f)), the residual pressure became negligible, the injection was regular at the low speeds, and there was not the phenomenon of "missing" on every other revolution. With the particular pump tested, the injections at the high speeds became irregular. This irregularity was caused, no doubt, by the fact that the intake manifold of the pump was not designed to take care of the violent pressure fluctuations transmitted to the intake manifold at cut-off when the check valve was removed. Increasing the pressure of the fuel in the intake manifold of the pump decreased the irregularity. Other pumps tested at the laboratory without the check valve have shown regular injections over the whole range. The disadvantages of omitting the check valve have been discussed in references 2 and 3. They consist chiefly of a decrease in fuel quantity for constant throttle setting as the pump speed is increased and, as the present tests have shown, of irregularities at high speeds unless a suitable damping arrangement is provided.

CONCLUSIONS

The following conclusions are presented for the type of pump tested:

1. A multicylinder fuel-injection pump can be so constructed that even after the pump has seen considerable service the distribution between the different cylinders does not vary by more than ±3.0 percent for all conditions of throttle above one-half throttle setting and for all speeds that are expected to be used in practice.

2. For loads of one-tenth throttle or less the variation in distribution may be as high as ±17 percent of the fuel quantity being injected although, in general, the distribution should not vary more than about ±10 percent under this low throttle setting.

3. When the individual cylinders are so adjusted as to give good distribution, the time rate of discharge curves for all cylinders are quite similar.

4. Poor seating of the injection-valve stem results in variation in residual pressure in the injection tube and in the initial rates of discharge.

5. Irregularities in the injection from each individual cylinder will occur at low throttle settings, at low speeds, or both because of variations in the residual pressure in the injection tube.

6. The irregularities mentioned in conclusion 5 can be decreased by decreasing the injection-valve opening pressure, by maintaining the residual pressure in the injection tube close to the injection-valve opening pressure, or by eliminating the check valve between the injection pump and the injection tube.

7. If no check valve is used between the injection pump and injection tube, irregularities may occur at high pump speed unless the intake manifold of the pump is of sufficient size to dissipate quickly the energy of the fuel in the injection tube at the instant of cut-off.

8. The regularity of injection is increased by the using of a very stiff injection-valve spring or by limiting the stem lift.

9. The lapped shoulder on the pump check valve gives a more rapid drop in pressure at injection cut-off but tends to increase the irregularity of injection at low speeds.

10. The type of injection valve used, provided that the seats are in good condition, has little effect on the distribution of a multicylinder pump.

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
LANGLEY FIELD, VA., *April 9, 1935*.

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